National Aeronautics and
Space Administration

Office of Biological and Physical Research

“EGG”-CEPTIONAL SUCCESS FOR AVIAN FACILITY ON ISS

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

Over the decades since the first space flight, researchers have discovered that a low-gravity environment has multiple and variable effects on the human body. Because relatively few humans are exposed to a microgravity environment, researchers often use animal models to obtain useful data that can be applied to human problems. One key area of interest is how microgravity affects normal development.

What is NASA doing?

The Avian Development Facility (ADF) was designed to incubate up to 36 Japanese quail eggs, 18 in microgravity and 18 in artificial gravity, so that the two sets of eggs are exposed to otherwise identical conditions, the first time this has been accomplished in space. Eggs are preserved at intervals to provide snapshots of their development for later analysis. Quails incubate in just 15 days, so they are an ideal species to be studied within the duration of Space Shuttle missions. Further, several investigators can use the same specimens.

The ADF originated in NASA’s Shuttle Student Involvement program in the 1980s and was developed under the NASA Small Business Innovation Research program. In late 2001, the ADF made its first flight and carried eggs used in two investigations:

- development and function of the inner-ear balance system in normal and altered gravity environments and
- skeletal development in embryonic quail.

Quail eggs are small (shown above at actual size) and develop quickly, making them ideal for space experiments. The Avian Development Facility supports 36 eggs in two carousels (below), one of which rotates to provide a 1-g control sample for comparing to eggs grown in microgravity.

What are the benefits?

Bones from the quail eggs are being analyzed for changes in mineralization, cell cycle timing, collagen synthesis, rate of bone formation, and the conversion of cartilage to bone during development. The ears are being analyzed to determine whether microgravity affects the development of the balance organs and what changes may take place in how they connect to the nervous system. The results from both studies should yield fundamental insights into basic animal development.

What is next?

Investigations with the ADF specimens continue. The ADF itself is now flight-qualified hardware available to support future investigations on the Space Shuttle or the ISS. With minor modifications, it can also support research on insects, plants, and fish.

NASA contact: Dr. David Liskowsky (202-358-1963)

National Aeronautics and
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Office of Biological and Physical Research

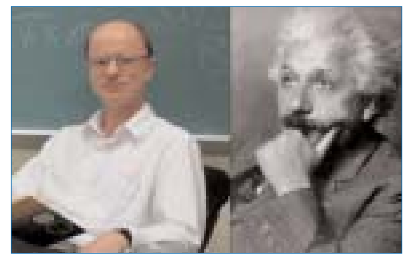
WAS EINSTEIN WRONG? SPACE STATION MAY FIND OUT

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

Einstein's Theories of Relativity have withstood a wide range of tests in the more than 90 years since they were first offered. Although they are widely accepted as fact, significant aspects regarding gravity are unverified because testing is not possible deep within Earth's gravitational field. Further tests are needed because

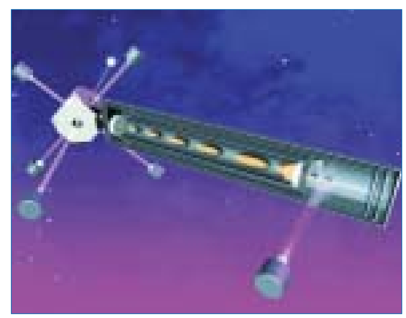
- gravity is one of the four known fundamental forces of nature and thus requires the best possible verification of our theories;
- the better we understand gravity and the implications of our observations regarding it, the more likely we will be to unify it with the other three forces; and
- any verifiable violation of the Theory of General Relativity is potentially fatal and would require developing a new theory of gravity.



Alan Kostelecky of Indiana University has analyzed the experiments testing Einstein's theories that can be performed on the ISS with high-resolution clocks.

What is NASA doing?

There are two initiatives in NASA to push the envelope of observations of gravity. The Office of Biological and Physical Research has supported laboratory-style investigations of general relativity for decades. The Office of Space Science, on the other hand, has recently formed a Fundamental Physics thrust that includes gravity and general relativity as prime subjects for exploration. This discipline supports gravity wave detection, investigation and modeling of high-density cosmological objects like black holes and neutron stars, and tests of general relativity like Gravity Probe B. Tests of the equivalence principle, such as the Satellite Test of the Equivalence Principle and Laser Lunar Ranging, are ongoing. Also, both ground-based laboratory and theory investigations of general relativity are supported. Now NASA is planning to place high-precision clocks on the ISS to improve the tests of gravity theories.



The Primary Atomic Reference Clock in Space experiment will test predictions of Einstein's theories of relativity regarding the fundamental nature of time and space. It will become the most accurate clock in the world, with performance disseminated worldwide through the Global Positioning System.

What are the benefits?

NASA provides investigators with a unique environment for testing this weakest of the natural forces. Test precision advances ranging to one part in one million aboard the ISS will give scientists considerable new knowledge of the properties of gravity. Entirely new ranges of test parameters can be explored in this "gravity-free" environment.

What is next?

NASA is planning to fly atomic clock experiments such as the Primary Atomic Reference Clock in Space (PARCS) on the ISS to test general relativity predictions. As well as supporting experiments requiring precise time standards, PARCS will open the way for experiments requiring the use of similar devices. In addition, Gravity Probe B is scheduled to test aspects of Einstein's theory of relativity in April 2003.

NASA contact: Dr. Mark Lee (202-358-0816)

MIMICKING THE BIRTH AND GROWTH OF PLANETS AND RINGS

Why is it important?
Understanding the release of dust and the rebound of colliding particles is crucial to understanding the evolution of planetary rings and the origins of the planets themselves. Collisions between the small particles in planetary rings occur at very low speeds, often less than 2 feet per minute (1 cm/s). Similar collisions occur in the early stages of planet formation, when the colliding rock and ice particles are so small that there is very little gravitational pull between them. As a result, even slow collisions can result in material being ejected or the particles bouncing apart instead of sticking together.

What is NASA doing?
To study the question of low-speed dust collisions, NASA sponsored the COLLisions Into Dust Experiment (COLLIDE) at the University of Colorado. It was designed to spring-launch marble-sized projectiles into trays of powder similar to space or lunar dust. COLLIDE-1 (1998) discovered that collisions below a certain energy threshold eject no material. COLLIDE-2 was designed to identify where the threshold is.

The COLLIDE apparatus—largely developed and built by graduate students at Colorado—carries six Impactor Box Systems. Each launches a pellet at a different speed into a small tray of dust. All six systems worked well. The slowest impactor ejected no material and stuck in the target. The faster impactors produced ejecta; some rebounded, while others stuck in the target.

What are the benefits?
COLLIDE investigations support work in several areas, including the following:

- providing a broader context for interpreting ground-based research into planet formation and growth;
- producing a video record of unique impacts in microgravity for education purposes;
- providing graduate students, who did much of the engineering work, with valuable flight experience; and
- developing applications for space flight and experimentation.

What is next?
The data from COLLIDE-2 are being analyzed, and options for a third flight are being studied. A ground-based investigation, PRIME, is flying on the KC-135 low-g aircraft for tests that can be run in less than 20 seconds of low-g.

NASA contacts: Dr. Francis Chiaramonte (202-358-0693) or Dr. Brian Motil (216-433-6617)

PHYSICAL SCIENCES RESEARCH
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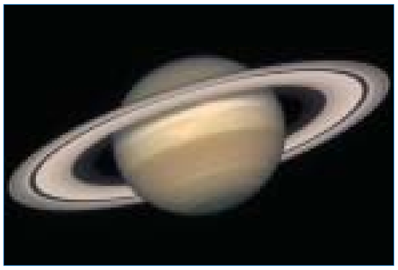
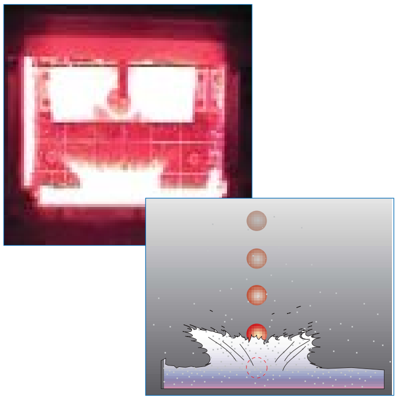


Clues to the formation of planets and planetary rings—like Saturn's dazzling ring system (above—may be found by studying how dust grains interact as they collide at low speeds. In COLLIDE-2, scientists nudged small projectiles into dust beds and recorded how the dust splashed outward (below). As depicted in the drawing, the projectile came from the top of the video frame.



National Aeronautics and
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SNIFFING OUT AIR QUALITY WITH AN ELECTRONIC NOSE

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

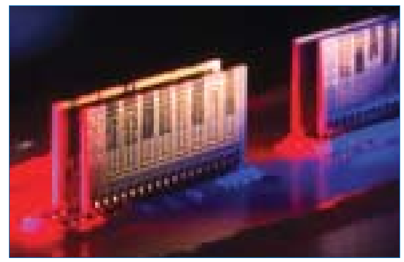
Why is it important?

Air quality monitoring is a priority when operating in closed environments such as the International Space Station (ISS) or many specialized workplaces on Earth. Rapid detection of deadly chemicals or overheating electrical equipment has been done in the past by the crew's collective sense of smell. However, the human nose becomes numb to pungent smells after a short time. We need a reliable nose that is always on duty and never becomes insensitive to dangerous odors.

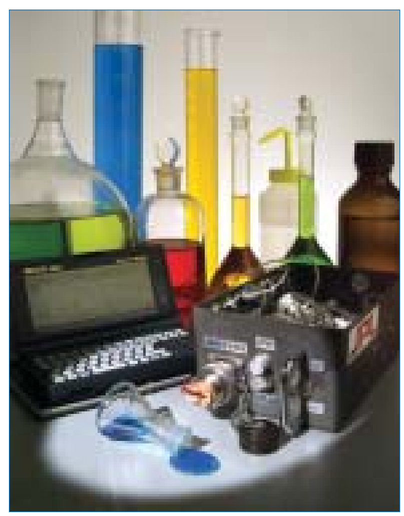
What is NASA doing?

Margaret Amy Ryan and a team of scientists and engineers at NASA's Jet Propulsion Laboratory (JPL) have developed an electronic nose that is similar to our own noses in the way it reacts to certain chemicals. The active parts are 32 sensors, each with a different mix of polymers saturated with carbon. When certain chemicals latch onto a sensor, they change how the sensor conducts electricity. This signal tells how much of a compound is in the air.

The electronic nose flown aboard STS-95 in 1998 was capable of successfully detecting 10 toxic compounds. This device can potentially reduce the health risks for astronauts on the ISS by detecting toxic chemicals; it can also help them determine when the air is breathable again.



ENose sensors (above) and their support system compose a package about the size and weight of a large paperback book. The sensors are tailored to conduct electricity differently when an air stream carries a particular chemical across them. JPL has designed and built a 3-pound flight version (below, with palm-size control and data computer).



What are the benefits?

The electronic nose is an exciting technology with many potential applications on Earth:

- food processing, to monitor food quality and freshness;
- industry, in process and quality control;
- medicine, as diagnostic tools;
- agriculture, as plant growth monitors;
- workplace and environmental safety; and
- bioterrorism early warning.

What is next?

The JPL team is improving the electronic nose in several ways:

- adding 15 compounds to the detection list,
- creating new software to analyze data in a way that classifies the characteristics and class of a compound,
- reducing the mass and volume of ENose to one-half of the version flown on STS-95, and
- increasing sensitivity and extending capability to separate mixtures.

NASA contact: Dr. Charlie Barnes (202-358-2365)

EYE TRACKING BRINGS VISUAL PERCEPTION INTO FOCUS

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

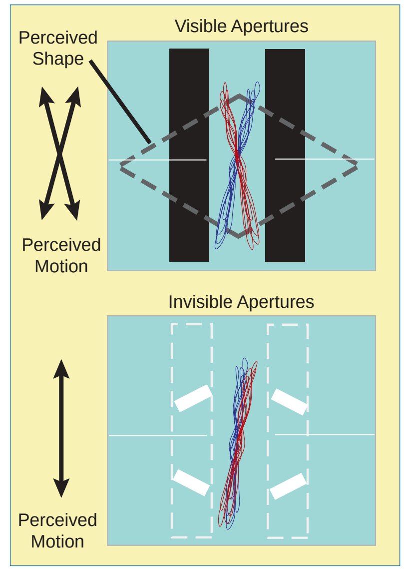
For air traffic controllers, pilots, astronauts, and others, the ability to track a moving target amidst many nontargets is essential. Perceptual errors during critical flight maneuvers—such as landing at night or docking with a space station—can lead to a disaster. NASA research into the link between eye movements and visual perception has application for the improved training and safety of anyone who depends on accurate vision and motor control.

What is NASA doing?

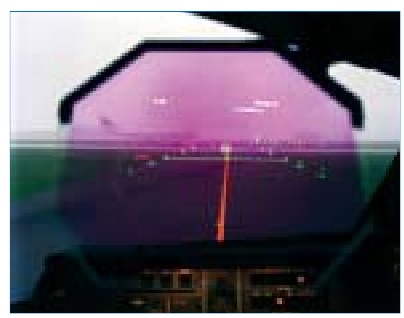
Dr. Leland Stone and other researchers at NASA Ames Research Center adapted computer monitors and infrared video cameras to measure eye movements without having to affect the crewmember. A computer screen provides moving images that the eye tracks while the brain determines what it is seeing. A video camera records movement of the subject's eyes. Researchers can then correlate perception and response. A particular concern is how returning from the microgravity of orbit to Earth can affect an astronaut's ability to fly safely.

Early results challenge the accepted theory that "smooth pursuit"—the fluid eye movement that humans and primates have—does not involve the higher brain. NASA results show that

- eye movement can predict human perceptual performance,
- smooth pursuit and saccadic movement (jerky eye tracking in nonprimates) share some signal pathways, and
- common factors can make both smooth pursuit and visual perception produce errors in motor responses.



Test subjects perceive different images when a moving object is covered by a mask that is visible or invisible (above). Tracking air traffic through a head-up display (below) can be more challenging.



What are the benefits?

In a complex landing system like those of the Space Shuttle and advanced jetliners and other aircraft with head-up displays, the pilot must watch a computer-generated image superimposed on the view of the outside world and then move the joystick to line up with the target for a safe landing. Understanding how errors might occur will let NASA improve training and displays, and thus will enhance flight safety.

What is next?

NASA scientists are expanding their studies to include crew responses on joysticks. With advances in the eye tracking techniques, scientists can apply rigorous measurements to human responses and advance our understanding of visual perception.

NASA contact: Dr. David Tomko (202-358-2211)

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USING SPACE TO GET A SOLID FOOTING

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

Rip open a vacuum-packed pouch of coffee and you experience a fundamental aspect of soil mechanics or granular materials in general: once pressures are released, the grain assembly moves about freely, almost like a liquid. This can happen to saturated, loose sand in an earthquake or to grains in a silo. During soil liquefaction, a soil-water composite momentarily acts like a viscous liquid as particles lose contact with one another and the material is balanced by the water, allowing buildings to sink and tilt, bridge piers to move, and buried structures to float.

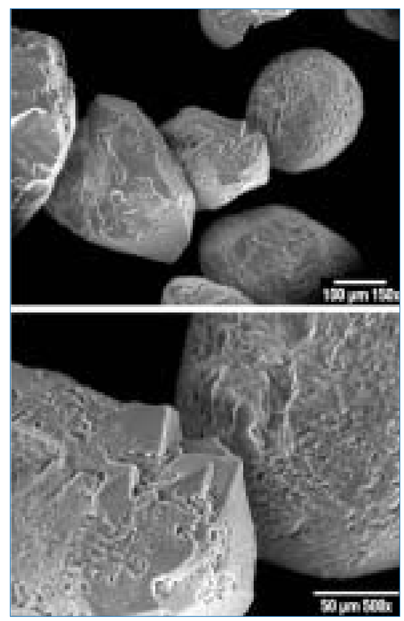
Detailed understanding of this phenomenon is needed to improve techniques for evaluating building sites here on Earth and to improve industrial processes with powdered materials. But on Earth, gravity-induced stresses complicate the analysis and change loads too quickly for detailed study, especially when instabilities occur.

Soil liquefaction during the October 17, 1989, Loma Prieta earthquake made this apartment building in San Francisco's Marina District sink.

What is NASA doing?

A fundamental model of soil behavior in earthquakes is not available in ground-based experiments. However, experiments in space allow low, confining stresses to be maintained for extended measurements. In the first two flights (1996, 1998), the Mechanics of Granular Materials (MGM) experiments showed the following results:

- volume change properties three times larger than predicted,
- very high stiffness properties nearly 10 times greater than predicted, and
- strength properties and instability phenomena quite different from theory.



What look like boulders are sand grains used in the MGM experiments. Countless microscopic faces cause friction until fluid pressure separates the grains and lets them briefly flow like a liquid.

What are the benefits?

Many natural and industrial processes will involve granular materials such as these:

- soil mechanics, geotechnical engineering;
- earthquake engineering;
- mining (open pits, strip mines, tunnels, shafts);
- grain silos, powder feed systems, coal, ash, pharmaceuticals, and fertilizers;
- coastal and offshore engineering;
- wind and water erosion of soil, slope development and decay, volcanic deposition;
- planetary geology; and
- microgravity handling of powders.

What is next?

The MGM-III experiments on STS-107 in 2003 will study earthquake liquefaction behavior. The hardware uses a new specimen reformation technique that allows multiple test runs. NASA is pursuing several investigations of different aspects of granular materials.

NASA contact: Dr. Francis Chiaramonte (202-358-0693)

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SPACE MAGNETS ATTRACT INTEREST ON EARTH

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

The familiar growth of plants—stems up, roots, down—is controlled by several mechanisms that we do not fully understand. We know that gravity is a primary controller, but we are uncertain how this is sensed and used within plants.

What is NASA doing?

Plant growth under low-gravity conditions in space has a been a keystone of fundamental space biology research. Current research indicates that the position of subcellular starch grains (amyloplasts) in plant cells plays a major role in a plant's sense of up and down. On Earth, amyloplasts in plant cells accumulate in the direction of gravity, causing a change in the cell's growth.

Amyloplasts can be moved by strong magnetic fields. Thus, a high-gradient magnetic field (i.e., concentrated at a specific point) could provide an artificial sense of "up" and "down" (not artificial gravity). As the root grows, the starch grains should be repelled by the magnetic gradient, causing the roots to curve in the direction of the displaced starch grains.

What are the benefits?

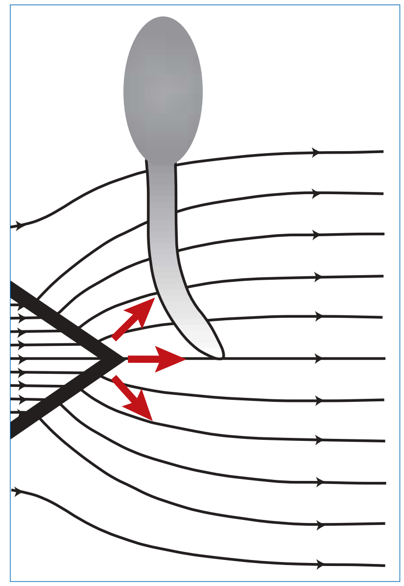
The BioTube/Magnetic Field Apparatus experiment addresses three major questions:

- Are amyloplasts (the starch grains) the organelles in plant cells that perceive gravity?
- Does the position or movement of the amyloplasts (caused by sedimentation on Earth or response to a high-gradient magnetic field in orbit) affect the root growth direction?
- Does gravity exert an effect on the deposition of cell wall material and the organization of plant cell organelles?

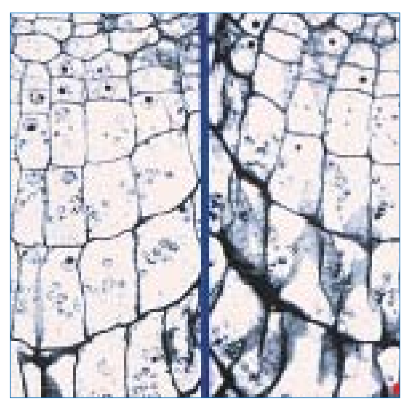
What is next?

The BioTube/Magnetic Field Apparatus investigation on the STS-107 research mission in 2003 will germinate and grow dry flax seeds in magnetic fields for 48 hours, then fix them for postflight analysis. As with all basic research, this study will contribute to an improved understanding of how plants grow and will have implications for improving plant growth and productivity on Earth. Similar flight experiments could be conducted on the ISS to increase our knowledge of how biological processes are affected by microgravity.

NASA contact: Dr. David Liskowsky (202-358-1963)



The tip of a wedge-shaped magnet will produce a strong magnetic gradient. Amyloplasts in the root tips should move away from the wedge edge, causing the root tips to curve (above). In simulated low-g, amyloplasts are randomly distributed (below, left), but displaced to one side when a magnetic field is applied (below right).



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NASA DEVELOPS SMALLEST, LIGHTEST CHEMICAL ANALYZER

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

Detecting trace levels of toxic chemicals before they reach harmful levels in the atmosphere is crucial to astronaut health on long missions and important for humans on Earth as well. One highly accurate and reliable tool that can quickly and automatically analyze complex mixtures of gases is the mass spectrometer. However, mass spectrometers are large, expensive devices demanding large power supplies. A handheld model was needed to monitor the environment outside the International Space Station (ISS) during spacewalks.

What is NASA doing?

Ara Chutjian and his colleagues at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, revolutionized the mass spectrometer by developing a miniature version just 3 inches tall and weighing about 4 ounces (a world record). With its associated gear, the system weighs only 3 pounds. This new Trace Gas Analyzer (TGA) was delivered to the ISS in February 2001. It can detect leaks of ammonia from cooling systems, propellant from thrusters, and air leaks from seals and micrometeorite holes in the spacecraft structure.

JPL technologists responded to a request for a quick, low-cost innovation by creating the smallest mass spectrometer yet produced for either human or robotic space flight (above, about actual size). It is used inside a handheld tool (inset) used by astronauts to check for leaks outside the International Space Station.

What are the benefits?

The U.S. Environmental Protection Agency uses mass spectrometers to monitor contamination from Superfund sites and factory emissions on Earth. These devices are only used sparingly because of their large size and high cost, and the samples are often brought back to labs for analysis. Chutjian and his colleagues hope to make their small, inexpensive unit available for readily detecting contaminants here on Earth. They are working with Consolidated Edison to develop field-deployable prototypes to detect PCBs (polychlorinated biphenyls) at contaminated sites.

What is next?

NASA will be able to use the combined gas chromatograph-mass spectrometer (GCMS) on human missions beyond low-Earth orbit. It would constantly monitor the spacecraft's air to detect the accumulation of hazardous gases such as carbon monoxide, benzene, and formaldehyde. The device can also be used to study the chemical composition of the materials collected from a Martian or asteroid surface. Chutjian and his colleagues are designing a second-generation mass spectrometer with 50 times the sensitivity and 3 times the resolution of the current model.

NASA contact: Dr. Charlie Barnes (202-358-2365)

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FIGHTING FIRE IN MICROGRAVITY

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

Since World War II, the most effective fire-fighting method has been high-pressure water sprays. How the droplets interact with the flames is largely unknown, partly because in Earth's gravity, a fire's heat generates air currents that make it difficult to study combustion. In space, however, water must be sprayed sparingly since it will not run off but can accumulate and be difficult to clean up.

What is NASA doing?

Environmental Engineering Concepts, Inc., and Arizona Mist, Inc., have partnered with the Center for the Commercial Applications of Combustion in Space (CCACS), a NASA-sponsored Commercial Space Center, to investigate the use of fine water mists in fighting a fire. The Water Mist experiment employs a two-part chamber with water on one side and a fuel-air mixture on the other. In microgravity, scientists will be able to study how a flame front moves into the mist and is extinguished, all without the convection that would occur on Earth. The first flight will be on STS-107 in 2003.

What are the benefits?

Replacing halon gases (banned by the 1987 Montreal Protocol) is expected to become an increasingly large part of the $2-billion-a-year fire suppression industry; the research being done on STS-107 is of great commercial interest. Potential benefits include the following:

- enabling the next generation of environmentally friendly and low-cost fire-fighting systems,
- minimizing water damage by using less water, and
- developing crew- and equipment-safe fire-control systems for use on spacecraft.

What is next?

Data from the investigations on STS-107 will be used on the ground to improve computer and mathematical models and allow detailed simulations to test theories and obtain more accurate results. Water mist investigations on the International Space Station will be able to use different water injection systems, droplet sizes, and other fire scenarios to support this important research.

Contact: Dr. F.D. Schowengerdt, Professor of Physics and Director of the Center for Commercial Applications of Combustion in Space (303-384-2091)

A low-gravity test of the Mist experiment shows (from top to bottom) a flame after ignition, encountering water mist, and slowing down and breaking up. Space experiments will allow longer, more definitive experiments than are possible on Earth.

The drawing to the right illustrates the fine scale of the droplets that will be formed in Water Mist as compared to 1-mm droplets formed by conventional water sprays. Small droplets have more surface area to absorb heat, but the dynamics of fire extinction are poorly understood.

IT'S A FILTER; IT'S A SPONGE

PHYSICAL SCIENCES RESEARCH
BIOASTRONAUTICS RESEARCH
FUNDAMENTAL SPACE BIOLOGY
SPACE PRODUCT DEVELOPMENT

Why is it important?

Zeolites are porous crystals that can act as storage cells until they are heated and release their contents. Zeolites (zeo lithos, "the rock that boils") are a $2-billion-a-year component of the world's trillion-dollar chemical processing industry worldwide. Virtually all of the world's gasoline is produced or upgraded using zeolites. Even a 1-percent improvement in the yield of gasoline from oil zeolites could have an economic impact exceeding tens of millions of dollars. However, gravitational effects on Earth restrict zeolites to the size of bacteria, thus limiting studies of their structures.

What is NASA doing?

The Center for Advanced Microgravity Materials Processing (CAMMP), a NASA-sponsored Commercial Space Center, is working to improve zeolite materials by using the microgravity of Earth orbit. Flights in 1992, 1993, and 1995 grew larger, higher quality zeolites than were possible on Earth. Studies continue with a Zeolite Crystal Growth Furnace Unit aboard the ISS and a similar unit on the STS-107 research mission in 2003.

What are the benefits?

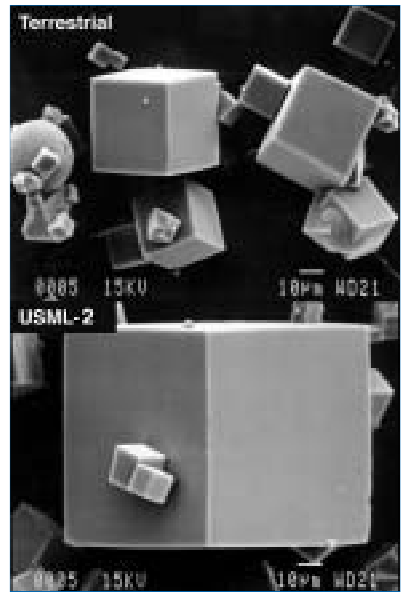
An exciting long-range possibility is to use zeolites to store and transport new, environmentally friendly fuels such as hydrogen. Current applications include the following:

- petroleum and petrochemical processing;
- animal feed supplements, decontamination of radioactive wastes, and a range of household products such as air-fresheners, kitty litter, and laundry detergents;
- air and water filters that help clean up the environment; and
- fillers for composite paper, rubber, plastics, or ceramics, and specialty lightweight ceramic and concrete products.

What is next?

When enough is known about how to manipulate both the nucleation and growth of zeolites, CAMMP can custom-design them for specific applications and reduce production costs and pollution. CAMMP plans to target zeolite membranes toward reactions—isomerization, dehydrogenation, and desulfurization—that are critical to the worldwide processing of petroleum and petrochemical products. In addition, novel applications are being developed to use zeolite membranes to separate and purify gases and liquids for pollution control.

Contact: Dr. Al Sacco, Director of the Center for Advanced Microgravity Materials Processing (617-373-7910)



Zeolite crystals grown on Earth (top) are smaller than those grown by Dr. Sacco on the Space Shuttle in 1994. What appears to be solid blocks are quite porous, as illustrated by the drawing (below). Understanding the exact atomic structure and how to control it are keys to tailoring zeolites to a wider range of uses.